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The γ activity from ^{11}Li beta decay

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Résumé. — Les énergies et les intensités absolues des raies γ consécutives à la désintégration β de ^{11}Li ont été mesurées. La transition β vers le niveau fondamental du ^{11}Be n'est pas observée. Le pourcentage de désintégration β ne conduisant pas à l'émission de particules retardées n'est que de (5,2 $\pm$ 1,4) %. On observe de nouvelles voies de neutrons retardés vers des états excités de ^{10}Be et on en déduit la probabilité totale d'émission de neutrons retardés.

Abstract. — The energies and absolute intensities of the γ-rays from the β-decay of ^{11}Li are measured. There is no sizable β branch to the ^{11}Be ground state. Only (5.2 $\pm$ 1.4) % of the β-decay strength does not lead to β-delayed particle emission. New β-delayed neutron branches to excited states of ^{10}Be are observed and the total delayed neutron emission probability is deduced.

Since its first observation [1], the ^{11}Li isotope has been actively studied. A 8.5 $\pm$ 0.2 ms half-life [2] and a 40.94 $\pm$ 0.08 MeV mass excess [3] have been measured. Its β-delayed total neutron emission probability [P_n = (60.8 $\pm$ 7.2) %] has been observed [2]. More recently, the neutron energy spectrum has been measured [4] which led to the first observation of β-delayed multiple neutron emission reported with a probability of P_{2n} = (9 $\pm$ 3) % value [4]. A sizable probability of β-delayed light charged particle emission is observed in a study currently in progress in our group [5].

In view of this wealth of information, it is somewhat paradoxical that the γ-activity of ^{11}Li had never been observed previously. This work was thus undertaken to measure the energy and absolute intensity of the various γ-rays emitted from the β-decay of ^{11}Li. From the present measurements, a new value for the β-delayed neutron emission probability is deduced which resolves the discrepancy between the earlier P_n measurement [2] and a recent theoretical estimate [6].

The experimental method is the same as described in our report on γ-activities from neutron-rich Na isotopes [7]. To summarize it, a pulsed beam of 24 GeV protons from the CERN synchrotron ([1]), induces nuclear fragmentation in a target of a heavy element, in the present case Ir. The recoiling nuclear fragments are thermalized in heated graphite, out of which the alkali elements selectively diffuse. The selectivity is enhanced by a surface ionization mechanism. At last, alkali ions are extracted and analysed by a mass spectrometer. This insures a complete selectivity in Z and A for the collected ions. The resulting γ-activity measured with a Ge(Li) detector is observed in coincidence with the beta activity detected by a plastic scintillator.

As an improvement over our previous work [7], three pieces of information are stored on tape for each β-γ coincidental event : the γ energy (E), the time (T) elapsed between the proton beam burst and the detection of the β-γ coincidence, and the time between the β and γ signals. Off line analysis of the data allows the constitution of E spectra according to the T parameter in order to discriminate between activities of different half-lives.

Figure 1 shows a γ energy spectrum with no restriction on T. As a result, γ-rays from the 8.5 ms ^{11}Li coexist with the 2 125 keV γ-ray from its 14 s ^{11}Be daughter.

One major aim of this work was to measure the absolute intensity $I\gamma$ of the observed γ-rays. The abso-

([1]) With a typical intensity of 2×10^{12} protons every 2.4 s.

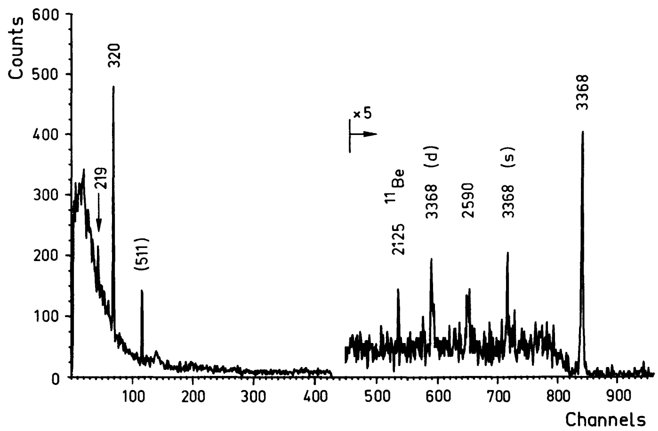

Fig. 1. — γ-ray spectrum observed in the decay of 8.5 ms ^{11}Li. Peaks are labelled in keV and their origine are indicated in table I. (s) and (d) stand for single and double escapes.

lute efficiency of the Ge(Li) detector was determined from calibrated sources of ^{56}Co, ^{85}Sr and ^{203}Hg with an estimated uncertainty of 12 %. The measurement of the number of decaying ^{11}Li ions collected was more difficult. It was determined in two ways : i) before and after each data accumulating run, direct measurements were made of the number of ions collected from the mass spectrometer per beam burst, i. e. for a certain number of incident protons; ii) the β-activity was multiscaled to identify the β-particles due to the short-lived ^{11}Li from those due to background or long-lived descendants. From the efficiency of the β detector, the corresponding number of collected ^{11}Li ions was deduced.

Although the results from these two methods were found to agree within 10 %, a more realistic estimate of 20 % was retained for the uncertainty on the number of ^{11}Li ions collected.

Table I lists the γ-activities observed and their absolute intensities. Three conclusions can be readily drawn from these results :

1) The intensity of the 2 125 keV γ-ray due to the β-decay of the daughter ^{11}Be nucleus, with a known [8] $I\gamma = (33 \pm 3)$ %, is fully accounted for by the measured intensity of the 320 keV γ-ray activity from the

Table I. — *γ activities observed from the β decay of* ^{11}Li.

$E\gamma$ (keV)	$E_i \to E_f$ (keV)	$I\gamma$ (^{a}) (%)
—		—
219	6 179 → 5 960 in ^{10}Be	0.95 ± 0.35
320	320 → 0 in ^{11}Be	5.2 ± 1.4
(2 125) (^{b})	2 125 → 0 in ^{11}B	1.8 ± 0.7
2 590	5 958, 5 960 → 3 368 in ^{10}Be	3.5 ± 1.0
2 811	6 179 → 3 368 in ^{10}Be	1.65 ± 0.70
3 368	3 368 → 0 in ^{10}Be	21 ± 6

(^{a}) The uncertainties include estimated uncertainties of 20 % for the number of collected ^{11}Li ions and 12 % for the Ge(Li) efficiency.

(^{b}) This 14 s γ activity from ^{11}Be decay is listed here for intensity comparison with the 320 keV γ-ray from the beta decay of ^{11}Li (see text).

decay of the first excited state of ^{11}Be which is the only bound excited state against particle emission [8]. Therefore, no sizable β branch to the ^{11}Be ground state is observed within the experimental uncertainties, as expected for a $(1/2)^- \to 1/2^+$ β transition.

2) Only (5.2 ± 1.4) % of the β-decays strength of ^{11}Li, which feeds the 320 keV level of ^{11}Be, does not give rise to β-delayed particle emission. All the remainder, which populates the other excited states of ^{11}Be, must then lead to one or several channels of particle emission, ^{10}Be + n, α + ^{6}He + n, ^{9}Be + 2 n, 2 α + 3 n, ^{8}Li + t.

As a result, the total particle emission probability is thus deduced to be

$$P_{1n} + P_{2n} + P_{3n} + P_t = 94.8 \pm 1.4\ \%.$$

Our current study of β-delayed light charged particle emission indicates a probability of the order of 5 % for the emission of 2 α or α + ^{6}He and a negligible one for ^{8}Li + t. This leads to a total delayed neutron intensity per beta disintegration of ^{11}Li,

$$(P_n = P_{1n} + 2\,P_{2n} + 3\,P_{3n}),$$

varying from 95 to 105 %, depending on whether the emission of α or ^{6}He-particles is associated with 1n or 3n emission.

This value is in strong disagreement with the only earlier measurement [2] which determined P_n as the ratio of the measured numbers of detected neutrons to β-particles. Whether a systematic error was introduced by an incorrect $P_n(^9\text{Li})$ normalizing value, by an inaccurate estimate of the efficiency for high energy neutrons, as suggested by Barker and Hickey [6], or by an improper determination of the fraction of β counting due to ^{11}Li as opposed to the background remains unclear. However it is felt that the new value, which is in qualitative agreement with a theoretical estimate [6] should be free of systematic errors for the following reasons : i) the number of decaying ^{11}Li has been measured consistently by two independent methods described above, ii) the neutron branching to the 2^+ state of ^{10}Be of (14 ± 5) % (see Fig. 2) is in good agreement with the independent measurement of Jonson and his coworkers [9] who give a value of 11 %, with an estimated uncertainty of half of that value.

The observed γ-rays from ^{11}Li decay give evidence for the population by β-delayed neutron emission of at least some of four states of ^{10}Be lying around 6 MeV excitation energy. Only an upper limit can be set for the feeding of the 6 263 keV level but the two γ-rays associated with the decay of the 6 179 keV level are observed. The γ-rays from the doublet of levels at 5.96 MeV, only 1.6 keV apart, cannot be resolved but a transition between this doublet and the 3 368 keV 2^+ level is observed. The β-delayed neutron feeding of a

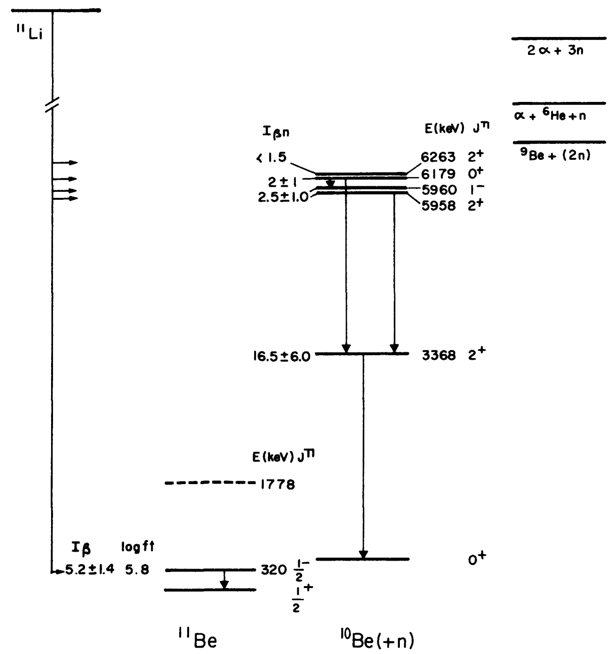

Fig. 2. — A partial β-decay scheme of ^{11}Li as established from the observed γ-activities. Beta decay intensities are given per 100 disintegrations of ^{11}Li.

^{10}Be level is defined as the difference between the γ intensities from and to this level.

Figure 2 summarizes the γ transitions observed and shows the β and β-delayed neutron intensities measured. It is clear that the major part of the β-decays, which goes unobserved in the present experiment, feeds the ^{10}Be ground state through neutron emission.

Even if ^{11}Li is an extreme case due to the low energy thresholds of many particle emission channels, the present results are in agreement with more general trends described elsewhere for Na isotopes [10]. More specifically, for odd-Z elements, P_{1n} tends towards 100 % for odd-A isotopes as observed here, while for even-A isotopes, P_{2n} tends towards P_{1n} as observed for ^{32}Na [11].

In any case, the high probability of β-delayed neutron emission is clearly the dominant aspect of β-decay of very neutron-rich isotopes.

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